Experimental Demonstration of a Metro Area Network with Terabit-capable Sliceable Bitrate Variable Transceiver using Direct Modulated VCSELs and Coherent Detection

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Abstract: We experimentally demonstrate a disaggregated metro area network that includes new photonic devices, node architectures, and sliceable bandwidth/bitrate variable transceiver, transmitting up to 8×11=88 spatial/spectral channels for a total capacity of 1.676Tb/s.

1. Introduction

The telecom operators are looking at the optical metro area network (MAN) disaggregation approach because it entails cost-reduction while enabling the migration and upgrade of network components and avoiding vendor lock-in [1]. This approach should be encompassed with the corresponding photonic devices and technologies in order to be able to manage high traffic variance and high capacity (super-)channels at low cost and high power efficiency [2]. So, novel network architectures must be envisioned in combination with efficient photonic technologies [3].

In the framework of EU-H2020 PASSION project, we propose to approach a disaggregated MAN architecture with different hierarchy levels (HLs), from those close to the edge (HL4) up to the core (HL1) [4]. Lower level metro-aggregation nodes (HL4, aggregating traffic from edge nodes at HL5) are handling only spectrum and are based on simple wavelength blockers [5] (see Fig.1). HL3 nodes are transit switches with 25GHz granularity (using wavelength selective switches, WSSs) envisioning/enabling all-optical routing from HL4 nodes to HL2/1. HL2/1 nodes interfacing the core network adopt specific photonic switching technologies to support mutiple functionalities and granularities while handling spectral and spatial dimensions [6].

In terms of photonic transmission technologies, we propose alternative solutions adopting photonic integrated circuits (PICs) and novel emerging technologies, such as vertical cavity surface emitting lasers (VCSELs). In fact, we rely on implementing programmable sliceable bandwidth/bitrate variable transceivers (S-BVTs) using directly modulated VCSELs and integrated coherent receivers to provide a solution with reduced cost, power consumption and footprint [3].

In this paper, we demonstrate the performance achievable with the PASSION network approach. In fact, we deploy a 5-node network path including HL4, HL3 and HL2 nodes, featuring flexible spectral and spatial switching and covering up to 110km distance including a 25km 19-core multicore fiber (MCF). We experimentally validate the transmission of 11 spectral channels densely spaced (25GHz) over 8 different cores through that network when using 10G VCSELs in combination with an integrated coherent receiver. Furthermore, the programmability to configure HL3/HL2 nodes is also assessed.

2. Experimental setup

The experimental setup is shown in Fig.1. The transmission experiments are based on offline processing implemented in the programmable DSP Tx (DSP Tx 1, DSP Tx 2) modules using Python software, following the steps detailed in [8]. Adaptive bit/power loading is implemented using the Levin-Campello rate adaptive algorithm in order to test the maximum capacity that the system can offer. A 4-channel high-speed digital to analog converter (DAC) (up to 64 GSa/s and 13 GHz electrical bandwidth) is used to convert the digital OFDM signals and provide electrical analog signals. The OFDM signals after DAC 1 and DAC 2 are fixed to be running at 16Gbaud- and centered to 8GHz and feed the corresponding VCSELs (VCSEL1, VCSEL2). VCSEL1 is the actual signal under test, while VCSEL2 is used for generating a set of 10 dummy signals with 25GHz spacing for emulating the different

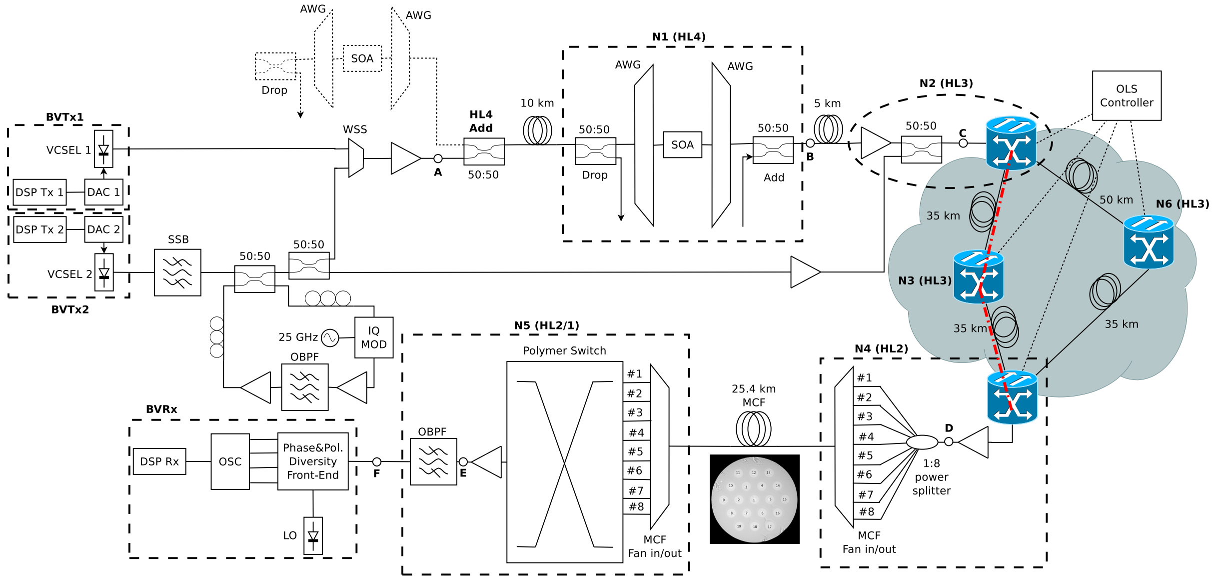

Fig. 1. Experimental setup.

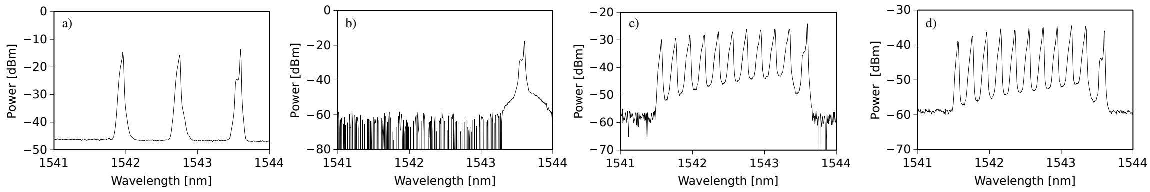

Fig. 2. Spectra at points A (a), B (b), C (c) and E (d)

spectral slices of the S-BVT. These dummy signals are generated by means of a recirculating frequency shifting technique [9]. There a seed signal (generated after single side band -SSB- filtering VCSEL2 output) is frequency shifted by the IQ modulator, amplified and re-injected into the modulator, generating a second frequency shifted signal. This process continues until terminated by one of the edges of the optical bandpass filter (OBPF) present in the loop. A couple of three-paddle polarizers are placed in the loop for aligning the state of polarization of the signals with the IQ modulator axes.

The optical signal generated by VCSEL1 is SSB filtered and injected to the network by means of an optical coupler that emulates the add channel operation of an HL4 node. Filtering is performed by a WSS that also includes selected dummy channels suitable for the 100GHz spacing of the HL4 nodes (see Fig.2a). The signals then traverse a 10 km standard single mode fiber (SSMF) spool that connects to another HL4 node. The latter node performs a pass-through operation by activating the semiconductor optical amplifier (SOA) corresponding to the channel in use and connects to a HL3 node by means of a 5km SSMF spool. The HL4 nodes are implemented by using 100GHz arrayed waveguide gratings (AWGs) and SOA for wavelength blocking [5] (see Fig.2b). At the HL3 node N2, the 25GHz-spaced dummy channels are added by means of a 50:50 coupler and transmitted over 2 links of 35km SSMF in the ADRENALINE testbed [10]. Optical spectra at this point is depicted in Fig.2c. Nodes N2, N3 and N4 are implemented using flexgrid-capable WSSs, so a superchannel of 275GHz is configured by the optical line system (OLS) controller. Note that node N6 does not have flex-grid capabilities [10] and, therefore, is discarded for the experiments. At the output of the N4 node there is a 1:8 power splitter and a 25.4 km MCF spool. The power splitter drives the signals to cores 1-8, which correspond to the central core plus 7 adjacent ones. Fibers of different lengths are connecting the 1:8 splitter with the MCF fan-in for decorrelating the signals present at the different cores. The MCF link ends at node N5 (HL2/1), implemented using a 16x16 polymer switch PIC prototype [7] and an OBPF that emulates the output (drop) multicast switch [6]. Note that this node configuration can handle 16 cores and emulate the drop of any channel in the range 191.9THz - 195.875THz [11]. So, it can manage up to 16×160=2560 channels with 25GHz spacing.

The receiver is an integrated coherent front-end, featuring polarization/phase diversities and a ring cavity laser prototype acting as local oscillator (LO) [12]. A real-time digital oscilloscope (OSC, running at 50 GSa/s and featuring 20 GHz bandwidth) is used for acquiring the IQ electrical signals corresponding to the two orthogonal states of polarization. Next the DSP Rx block is in charge of signal downconversion, equalization and data demodulation, following the steps detailed in [8]. This includes dispersion compensation and polarization handling for a reception agnostic to the state of polarization of the received signal.

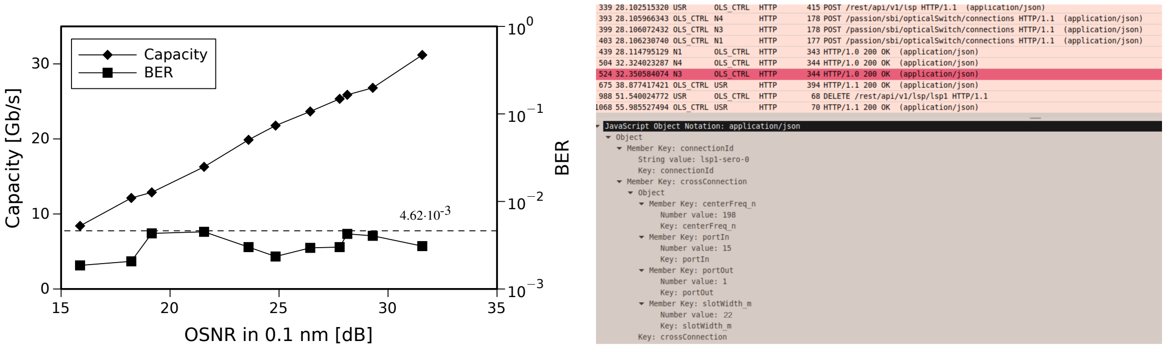

Fig. 3. Capacity vs OSNR for the back to back. Wireshark of the configuration of the network nodes.

Table 1. Capacity and BER for the signal under test at each point of the setup.

Point	B	C	D	F
Distance	10 km	15 km	85 km	110 km
Capacity	25.15 Gb/s	22.46 Gb/s	21.5 Gb/s	19.05 Gb/s
BER	$3.4{\cdot}10^{-3}$	$4.2{\cdot}10^{-3}$	$3.9{\cdot}10^{-3}$	$4.5{\cdot}10^{-3}$
OSNR in 0.1 nm	27.72 dB	26.55 dB	25.43 dB	24.19 dB

3. Results

For all the results reported, the bit error ratio (BER) obtained is within the range between 10^{-3} and $4.62{\cdot}10^{-3}$, corresponding to the threshold values for a standard hard decision forward error correction (FEC) featuring 7% overhead [13]. First, a back-to-back characterization is performed in terms of maximum capacity. Results are shown in Fig.3. The maximum capacity (31.2Gb/s) is attained for an optical signal to noise ratio (OSNR) value of 31.6dB and $3.09{\cdot}10^{-3}$ BER. In this case, capacity decreases almost linearly down to 8.41Gb/s for 15.87dB OSNR.

Next, we report the results for the entire network setup. Capacity and BER for the signal under test are summarized in Tab.1. There we can observe that at point B, after passing through the HL4 node, we obtain a capacity of 25.15Gb/s and 27.72dB OSNR, in line with back to back results. At point C, all the dummy channels are aggregated at HL3 node after two hops (15 km), attaining 22.46Gb/s with OSNR of 26.55dB, 1.2dB away from the back to back. After the HL3 segment, at point D, the accummulated distance is 85km, covering 4 hops. There we obtain 21.5Gb/s and 25.43dB OSNR (∼1dB penalty with respect to the back to back). Finally, at point F we obtain 19.05Gb/s and 24.19dB OSNR. This is 1.1dB away from the back to back. At this point, deactivating the dummy channels, we obtain 21.13Gb/s and $2.9{\cdot}10^{-3}$ BER, which is again in line with the back to back.

Fig.3 shows the screenshot of the protocol analyzer with the messages exchanged between the OLS controller and the corresponding network nodes. There it can be seen that the setup delay is 60.45s, while the delete delay is 4.44s. Also, details from the configuration of the nodes are shown, like the central frequency (n=198, 194.34THz) and bandwidth (m=22, 275GHz).

4. Conclusions

We have experimentally assessed a disaggregated metro area network able to handle up to 16×160 = 2560 spatial/spectral channels at different aggregation levels and granularities. An S-BVT based on direct modulated VCSELs and coherent reception is demonstrated to successfully transmit 8×11=88 spatial/spectral channels running at up to 19.05 Gb/s over this infrastructure, covering 110 km and amounting to a total capacity of 1.676 Tb/s.

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